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A New Numerical Treatment of Hohlraum Boundaries for ALE Rad/Hydro Codes

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A New Numerical Treatment of Hohlraum Boundaries for ALE Rad/Hydro Codes

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Abstract
Numerical treatment of the Laser Entrance Hole (LEH) region in hohlraums and halfraums with Arbitrary Lagrangian Eulerian (ALE) or pure Lagrangian codes is difficult near the Lagrangian boundary interface. For example, recent studies have focused on ALE methods for boundaries with rezoning to simulate the LEH window motion and the sliding contact between the window and the LEH edge. [1] We propose a technique for handling such boundary complications based on the inclusion of a wrap-around very-low density mesh structure. Additional ALE rezoning features such as material zone weighting are included to preserve numerical accuracy. We demonstrate the ability of ALE simulations using our technique to run to late time with very little user intervention. We benchmark our simulation results with experimental data from both two and three-dimensional halfraum experiments shots on the Helen and Omega Lasers.

I. Introduction

High-powered laser facilities such as NIF and LMJ place new requirements on optics protection from debris and shrapnel creating by the laser-induced dismantling of the target and target-related materials in the fusion chamber. Thus the final optics for both NIF and LMJ are protected by debris shields. However, it is important to determine the actual amount and characteristics of material that might strike the debris shields and diagnostics so that experiments can be planned in appropriate order with regards to debris shield replacement and diagnostic protection.

Traditionally, ICF codes are designed to predict early-time behavior of the hohlraum targets—on the order of the pulse length. In order to calculate chamber effects, we must develop ways to run the simulations out to very late times—on the order of 50 to 100 times the pulse length. A problematic area for such late-time hohlraum simulations is the region around the LEH. In this paper we describe a technique for modeling this region based on the concept of a wrap-around mesh very-low density mesh structure. We find this technique enables our late-time simulations for a variety of targets including halfraums and foils as well as hohlraums.

II. ALE Hydrodynamics

Many of the simulations of ICF experiments use radiation hydrodynamic codes. These codes are often coupled physics packages with ALE hydrodynamics. The ALE method allows for the problem to be run fully Lagrangian (mesh follows fluid) or fully Eulerian (fixed mesh) or performed on an arbitrary grid that is neither fully Lagrangian nor fully Eulerian.

ALE hydrodynamics generally follows a cyclic pattern:

- Lagrange step (predictor-corrector in time

- Mesh relaxation step (optional). Modification of the grid to prevent mesh tangling and other problems
- Advection step to interpolate the solution from the Lagrange grid to the modified grid.

III. Meshes

Figure 1 shows a typical configuration used to simulate early time halfraum/hohlraum physics. Here, the zoning in the wall is much finer than the zoning in the interior of the halfraum to allow for the dense wall material to “blow off” via Lagrangian motion as the wall is heated. The LEH is turned up at the edge to allow fine resolution and wall blow-off at the points at which the laser enters. Generally in early-time simulations the mesh in the immediate vicinity of the LEH has a fixed boundary.

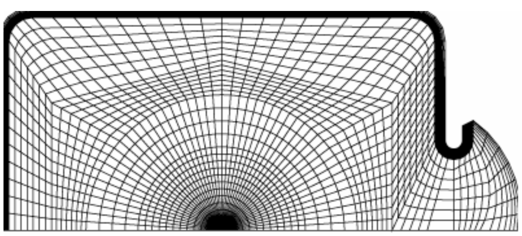

Figure 1. Traditional “early-time” halfraum mesh with LEH turned upward.

The problem with using such a mesh for late-time simulation occurs later in the problem as material blows off into the region outside of the LEH and eventually can experience collisions with other portions of the mesh. Also, freeing the LEH boundary region can cause problems.

Figure 2 shows the mesh several nanoseconds into the calculation when the ablated zones stream out the LEH with Lagrangian motion. As the calculation proceeds, the blown-off zones collide with the wall zones.

Some methods to ameliorate this situation include zoning though the LEH, communication between the blown-off zones and the wall zones, and special boundary zoning techniques. [1,2] However, a more useful technique for our simulations to wrap the entire problem in a low-density “air” mesh.

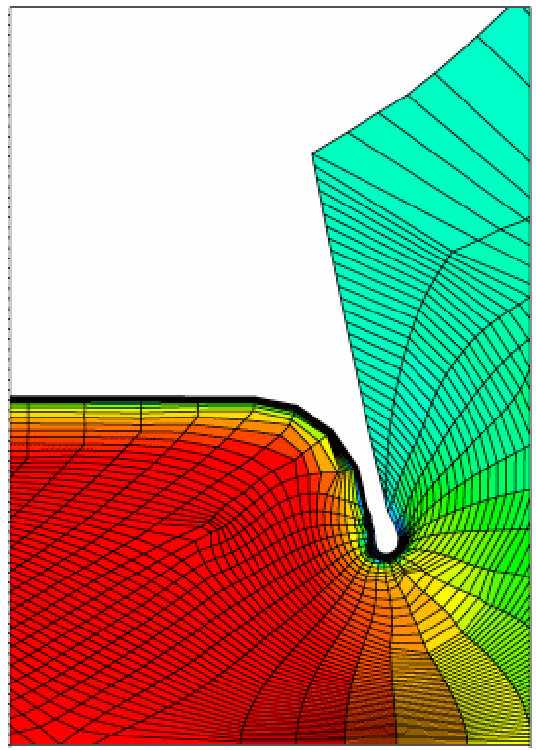

Figure 2. LEH Lagrangian blow-off on a traditional mesh can cause mesh tangling/collision problems in late-time simulations as the blow-off region comes into contact with other portions of the grid.

Figure 3 shows a portion of a sample air mesh for this same configuration. The additional of these external zones gives the ALE technique a region to expand into without mesh tangling or mesh collisions.

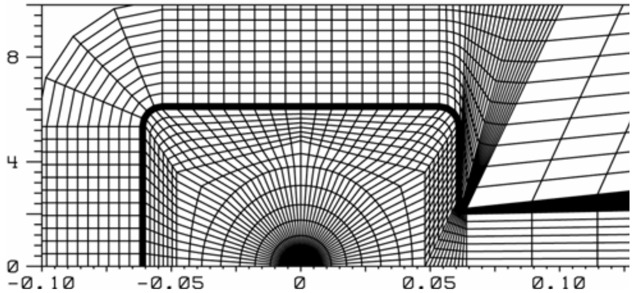

Figure 3. The same essential configuration as in Figure 1 is shown wrapped in an airmesh of zones to facilitate late-time simulations.

The additional of the air mesh does not affect the accuracy of the calculation. Additionally, by using special ALE techniques we can weight certain areas of the mesh (e.g., the wall region) more heavily than the surrounding air mesh zones to improve the accuracy and efficiency of the simulation.

IV. Application

As an application of our technique, we consider halfraum target with an open LEH turned outward as a flange. (Here, we show half of the target so that the interior and exterior walls are visible.) This target is representative of the hot halfraum geometry that is planned for NIF Early Light (1^{st} quad) operation. Figure 4 shows the three-dimensional geometry just after the laser that enters through the open LEH and strikes the back wall begins to ablate material.

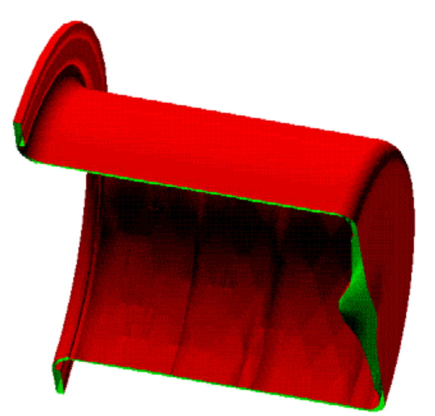

Figure 4. Cut-away view of a halfraum target with an open LEH. Green color indicates material being blown-off into the halfraum just after the laser starts to ablate material.

To protect the optics, we determine the direction of the majority of the mass of the material after the target disintegrates. Here, a large amount of the mass is contained in the flanges. Does this mass blow-off normal and strike the optics' debris shield?

By using our technique of wrapping the problem in the air mesh we are able to simulate this planned NIF experiment out to many times the pulse length. We are then able to post-process the simulation and determine the trajectory of the wall mass.

In Fig. 5 we show density contours at three different times on a logarithmic scale. From the figures (and from post-processing the simulation) we see that most of the flange material is directed vertically upward away from the optic.

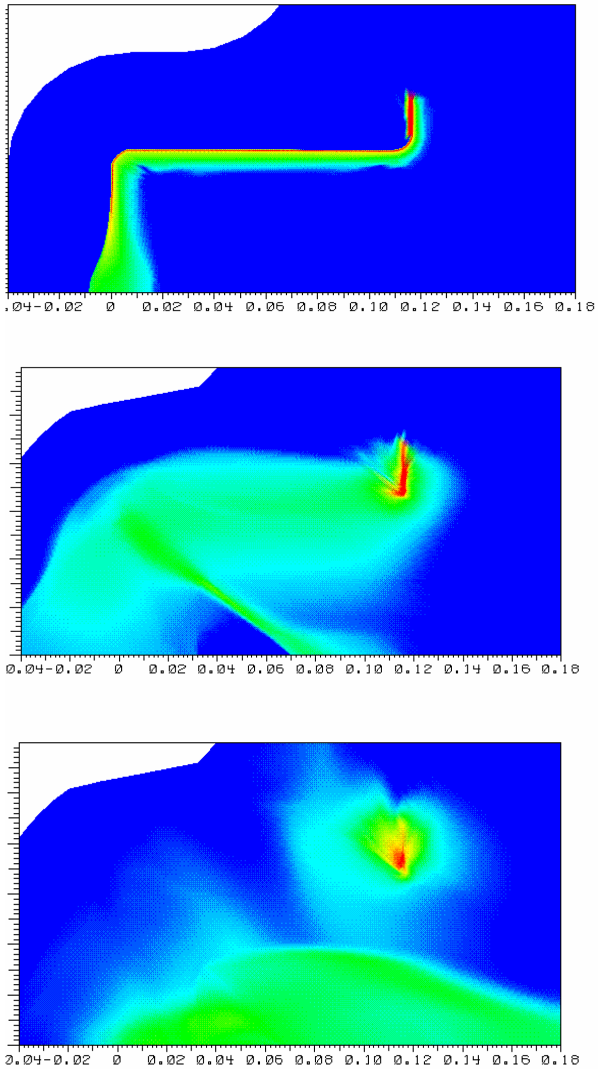

Figure 5. Filled density contours at 2, 5 and 10 ns. Density is represented on a logarithmic scale with red being the highest density, and blue being the lowest.

We have also run experiments on the HELEN Laser to benchmark our simulations. Here we surround a halfraum target with glass collection plates. As the target is dismantled by the laser pulse, the debris from the wall is collected and available for analysis. Preliminary analysis of this data shows good agreement with the simulations. These results will be presented in an upcoming paper.

V. References

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[2] D. Eder, A. Koniges, M. Tobin, and B. MacGowan, "Late-time simulation of the National Ignition Facility hohlraums, Nuclear Fusion,"submitted, 2003.

VI. Acknowledgments

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